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## SOLAR ANALOGS WITH AND WITHOUT PLANETS: $T_c$ TRENDS AND GALACTIC EVOLUTION

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**Abstract.** We explore a sample of 148 solar-like stars to search for a possible correlation between the slopes of the abundance trends versus condensation temperature (known as the  $T_c$  slope) both with stellar parameters and Galactic orbital parameters in order to understand the nature of the peculiar chemical signatures of these stars and the possible connection with planet formation. We find that the  $T_c$  slope correlates at a significant level with the stellar age and the stellar surface gravity. We also find tentative evidence that the  $T_c$  slope correlates with the mean galactocentric distance of the stars ( $R_{mean}$ ), suggesting that stars that originated in the inner Galaxy have fewer refractory elements relative to the volatile ones. We found that the chemical peculiarities (small refractory-to-volatile ratio) of planet-hosting stars is probably a reflection of their older age and their inner Galaxy origin. We conclude that the stellar age and probably Galactic birth place are key to establish the abundances of some specific elements.

### 1 Introduction

After the first planets were discovered, astronomers have been trying to understand if the stars hosting planets are chemically peculiar and even to search for chemical signatures of planet formation on the hosting stars atmospheres. Regarding the chemical peculiarities, the most significant result was obtained by Haywood (2008, 2009) and Adibekyan et al. (2012a,b) where a systematic enhancement in

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$\alpha$ -elements was found for most of the metal-poor planet hosts. Regarding chemical imprints of planet formation, the results are still feeding a lively debate.

Several studies suggested that the chemical abundance trend with the condensation temperature,  $T_c$ , is a signature of terrestrial planet formation (e.g. Meléndez et al., 2009; Ramírez et al., 2009). In particular, that the Sun shows “peculiar” chemical abundances because of the presence of the terrestrial planets in our solar system (Meléndez et al., 2009). Although these conclusions have been strongly debated in other studies (e.g. González Hernández et al., 2010, 2013, hereafter GH10,13), the main reason of the observed chemical peculiarities was not identified.

Here we explore the origin of the trend observed between  $[X/H]$  (or  $[X/Fe]$ ) and  $T_c$  using a sample of 148 solar-like stars from GH10,13. The more detailed analysis and complete results are presented in Adibekyan et al. (2014).

## 2 Data

Our initial sample is a combination of two samples of solar analogs (95 stars) and “hot” analogs (61 stars) taken from GH10,13. For 148 of these stars, Casagrande et al. (2011) provides the Galactic orbital parameters and the ages. Fifty-seven of these stars are planet hosts, while for the remaining 91 no planetary companion has been detected up to now.

The stellar atmospheric parameters and the slopes of the  $\Delta[X/Fe]_{SUN-star}$  versus  $T_c$  were derived using very high-quality HARPS spectra<sup>1</sup>. These slopes are corrected for the Galactic chemical evolution trends as discussed in GH10,13.

Throughout the paper we defined solar analogs as stars with;  $T_{eff} = 5777 \pm 200$  K;  $\log g = 4.44 \pm 0.20$  dex;  $[Fe/H] = 0.0 \pm 0.2$  dex. Fifteen out of 58 solar analogs in this sample are known to be orbited by planets.

## 3 Correlations with $T_c$ slope

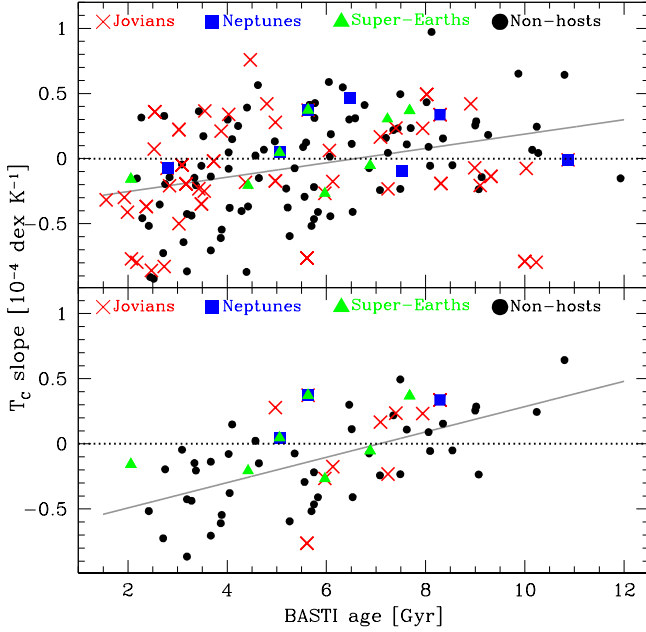
### 3.1 $T_c$ slope against stellar parameters and age

After a detailed analysis, we found that the  $T_c$  trend strongly relates (at more than  $4\sigma$ ) with the surface gravity and stellar age (see Figure 1): old stars are more depleted in refractory elements (smaller refractory-to-volatile ratios) than their younger counterparts. At the same time we found no significant correlation of the  $T_c$  slope with other stellar parameters.

Since for FGK dwarf stars in the main sequence one does not expect significant changes in their atmospheric chemical abundances with age, we are led to believe that the observed correlation is likely to reflect the chemical evolution in the Galaxy.

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<sup>1</sup>Zero slope means solar chemical composition, and a positive slope corresponds to a smaller refractory-to-volatile ratio compared to the Sun.



**Fig. 1.**  $T_c$  slopes versus ages for the full sample (*top*) and for the solar analogs (*bottom*). Gray solid lines provide linear fits to the data points.

### 3.2 $T_c$ slope and Galactic orbital parameters

Moving one step further, we found a tentative evidence that the  $T_c$  slopes correlate also with the mean galactocentric distance of the stars ( $R_{mean}$ ), which we use as a proxy of the birth radii. This trend is indicating that stars which have originated in the inner Galaxy have less refractory elements relative to the volatiles. This result qualitatively agrees with the recent observations of Galactic abundance gradients by Lemasle et al. (2013), where the authors used young Galactic Cepheids for the gradient derivations.

### 3.3 $T_c$ slope and planets

The Kolmogorov-Smirnov (K-S) statistics predict the  $\approx 0.21$  probability ( $P_{KS}$ ) that solar analogs with and without planets came from the same underlying distribution for  $T_c$  slope. At the same time, the same statistics predict a  $P_{KS} \approx 0.20$  probability that they stem from the same underlying age distributions. The latter can be seen in Figure 1. Moreover, planet host and non-host samples show a different distribution of  $R_{mean}$  –  $P_{KS} \approx 0.007$ . Clearly, the two subsamples are not consistent with respect to the mean galactocentric distance and age. Inter-

estingly, Haywood (2009) has already shown that (giant) planet host stars tend to have smaller  $R_{mean}$  and probably originate in the inner disk, which follow the same direction as our findings.

These results suggest that the difference in  $T_c$  slopes observed for solar analogs with and without planets is then probably due to the differences in their birth places and birth moment.

## 4 Conclusion

Our findings lead us to two interesting conclusions i) The solar analogues with planets in the solar neighborhood mostly come from the inner Galaxy (chemical conditions for their formation are more favorable?) and ii) the age and galactic birth place are the main factors responsible for the abundance ratio of refractory to volatile elements in the stars.

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## References

- Adibekyan, V. Z., Delgado Mena, E., Sousa, S. G., et al. 2012b, *A&A*, 547, A36
- Adibekyan, V. Z., Santos, N. C., Sousa, S. G., et al. 2012a, *A&A*, 543, A89
- Adibekyan, V. Z., González Hernández, J. I., Delgado Mena, E., et al. 2014, *A&A*, 564, L15
- Casagrande, L., Schönrich, R., Asplund, M., et al. 2011, *A&A*, 530, A138
- González Hernández, J. I., Israelian, G., Santos, N. C., et al. 2010, *ApJ*, 720, 1592
- González Hernández, J. I., Delgado-Mena, E., Sousa, S. G., et al. 2013, *A&A*, 552, A6
- Haywood, M. 2008, *A&A*, 482, 673
- Haywood, M. 2009, *ApJ*, 698, L1
- Lemasle, B., François, P., Genovali, K., et al. 2013, *A&A*, 558, A31
- Meléndez, J., Asplund, M., Gustafsson, B., & Yong, D. 2009, *ApJ*, 704, L66
- Ramírez, I., Meléndez, J., & Asplund, M. 2009, *A&A*, 508, L17